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Berkeley
California 94701

Research Note
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Hawaiian Treefern Harvesting Affects Forest Regeneration and Plant Succession

Michael G. Buck

Hawaiian treefern (hapu'u [*Cibotium* spp.]) forests of Hawaii consist of unique vegetation types. The treeferns sometimes form dense, almost pure stands in some locations but grow as understory to native tree complexes in other locations. Hawaiian treefern, notably Hapu'u pulu (*Cibotium glaucum* [Smith] Hook & Arnott), is highly prized for its fibrous main trunk, which is an interwoven mass of aerial roots extending from the base of each frond to the ground. This fibrous material absorbs a large amount of water, remains relatively resistant to decay, and is, therefore, an excellent medium for growing orchids and other flowers.[1]

In recent years, interest has in-
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Board of Land and
received an appli
treefern on 2956
private land in the
the island of Hawa

Because of the lack of knowledge of the treefern forest, the Board of Land and Natural Resources limited the harvesting to 150 acres (60.6 ha) for research purposes. As a result of the Board's decision, a study was designed to monitor the reestablishment of Hawaiian treefern and other woody and herbaceous vegetation over a period of years.

This note reports results of the study done in the Kilauea Forest by the Hawaii Division of Fo
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The effects of Hawaiian treefern (Hapu'u [*Cibotium* spp.]) harvesting on forest regeneration and plant succession were studied on 150 acres (60.6 ha) on the island of Hawaii, from 1972 to 1980. Results to date indicate that native species composition in the treefern forest is altered by harvesting activities. Heavy, uncontrolled harvest can result in extensive displacement of native plants by introduced species. With careful and controlled harvesting, however, invasion by introduced species can be minimized and a native plant community can be maintained.

Retrieval Terms: Hawaiian treefern, hapu'u, controlled harvest, regeneration

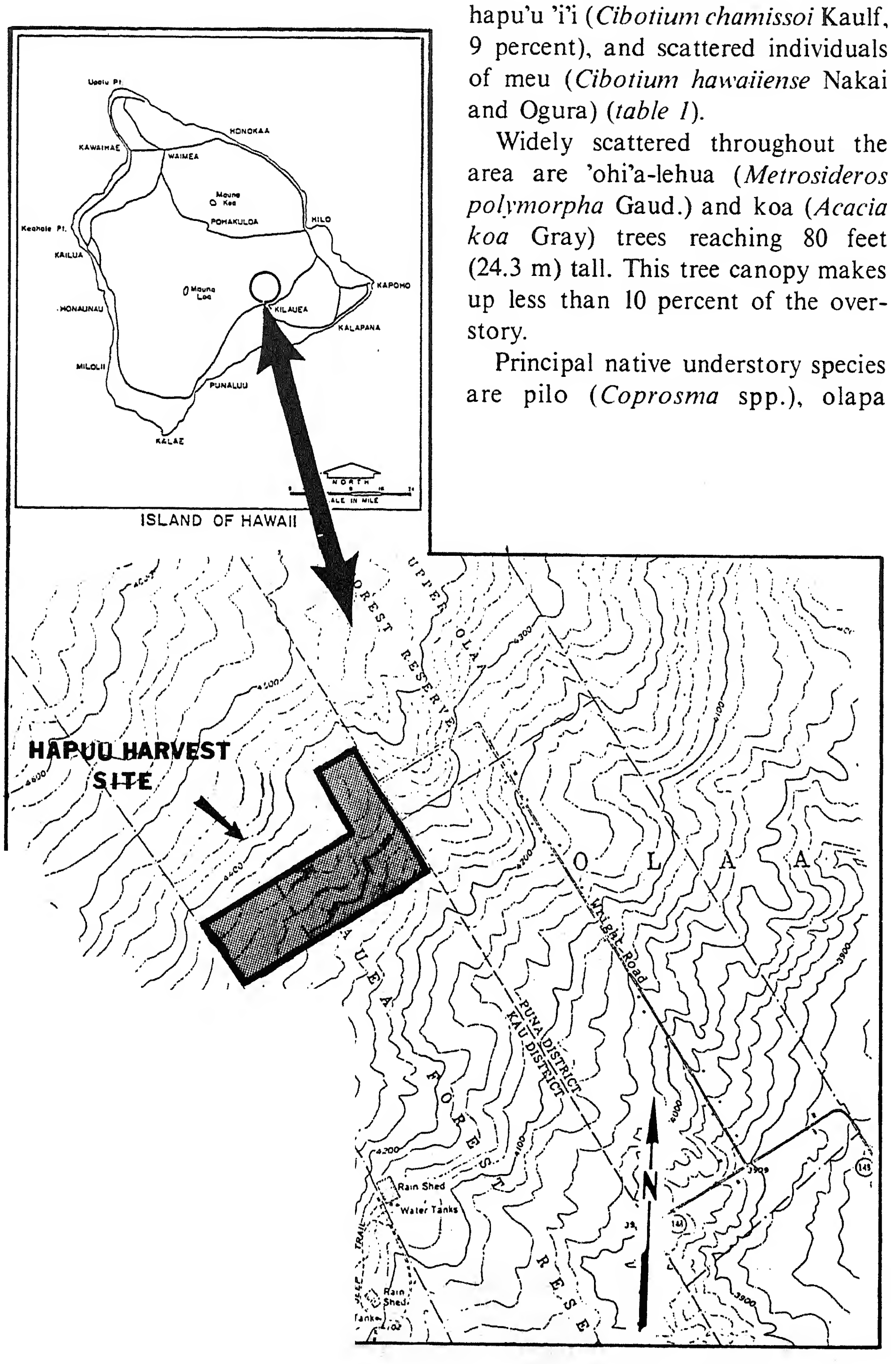
fall averages 110 inches (2790 mm). Topography is gently sloping with gradients of 0 to 10 percent.

The harvest area has been mapped as Puaula and Piihonua series soils.[3] These are well-drained soils formed on volcanic ash. The Puaula series is a silt loam averaging more than 60 inches (1.52 m) deep. The Piihonua series is a silty clay loam averaging more than 40 inches (1.02 m) deep. Erosion hazard is slight for both series.

The forest in the study area is predominantly Hawaiian treefern with canopy heights of 10 to 25 feet (3.05 to 7.62 m) covering 90 percent of the ground. Hawaiian treefern components are hapu'u pulu (90 percent), hapu'u 'i'i (*Cibotium chamissoi* Kaulf, 9 percent), and scattered individuals of meu (*Cibotium hawaiiense* Nakai and Ogura) (*table 1*).

Widely scattered throughout the area are 'ohi'a-lehua (*Metrosideros polymorpha* Gaud.) and koa (*Acacia koa* Gray) trees reaching 80 feet (24.3 m) tall. This tree canopy makes up less than 10 percent of the overstory.

Principal native understory species are pilo (*Coprosma* spp.), olapa (*Cheirodendron trigynum* [Gaud.] Heller), kawa'u (*Ilex anomala* H. & A.), mamaki (*Pipturus* spp.), and olomea (*Perrottetia sandwicensis* Gray). The native fern understory includes 'akolea (*Athyrium microphyllum* [Smith] Alston), *Asplenium contiguum* Kaulfuss, and ho'i'o (*Athyrium sandwichianum* Presl.). Introduced species in the harvest area include buddleja (*Buddleja asiatica* Lour.), blackberry (*Rubus penetrans* Bailey), thimbleberry (*Rubus rosaefolius* Sm.), and several members of the Juncaceae and Cyperaceae.



lauea Forest, Hawaii.

METHODS

In 1972, to assess the effects of harvesting, six line transects were established, using a straight fence line for a baseline. The fence separated a pasture from the southerly boundary of the harvest area. The transects were about 1300 feet (395 m) long and 720 feet (219 m) apart (*fig. 2*).

A total of 77 plots were established, one at every 100 feet (30.4 m) along the six transect lines. Plots were 20 by 20 feet (6 by 6 m) and were set up permanently to ensure precise relocation (*fig. 3*). The frequency of all plant species irrespective of height was tallied for ten 2- by 2-foot (0.61- by 0.61-m) subplots on the easterly side of each plot. Frequency was measured by a count of the subplots on which a species was present. Values obtained represent presence and absence in these subplots. Frequencies were compared by the McNemar test for significance of changes.

All woody plants more than 4.5 feet (1.37 m) tall and all Hawaiian treeferns more than 2 feet (0.61 m) tall from the ground to main bud tip, were tallied for each plot. The height and canopy status of each tallied plant were recorded. Canopy status, or stratification, indicated whether the plant was overtopped. Plant densities were compared for significance using the Wilcoxon Signed Rank Test.

Initial measurements were made in 1972, and remeasurements made in 1977, and in 1980.

Harvest Treatments

When harvesting first began, no restrictions were placed on the loggers. But when indiscriminate harvesting resulted, tight controls were quickly established. Three different conditions resulted from the controls imposed during the progress of the work: forest unharvested; light controlled harvest; and heavy uncontrolled harvest:

Unharvested—About 25 acres (10.1 ha) remained undisturbed throughout the study. This area is represented by 13 plots in transect 6 (*fig. 2*).

Controlled harvest—About 100 acres (40.4 ha) were harvested with these conditions:

a. Only the prostrate treefern or portions of it on the ground were removed. Standing treeferns were not cut, except in skid trails (*fig. 4*).

b. Lateral skid trails were about 200 feet (61 m) apart and logs were hand-guided over these trails.

c. One D-4 tractor was used to haul an 8- by 16-foot (2.4- by 4.9-m) sled carrying Hawaiian treefern out to the main skid trail.

d. Live treefern tops were scattered on skid trails and other openings caused by the logging activities (*fig. 5*). These tops consisted of a portion of fibrous trunk with an active bud tip. Twenty to 30 percent of the treefern overstory was removed in the light controlled harvest area as a result of logging activities. This removal was spread randomly over the harvest area with large openings usually confined to skid trails. Understory vegetation and ground cover were disturbed where treefern logs were removed. This area is represented by 52 plots in transects 2 through 5.

Uncontrolled harvest—About 25 acres (10.1 ha) were harvested with no restrictions on logging practices. No attempt was made to minimize harvesting disturbance and some standing treeferns were cut. Fifty to 60 percent of the treefern overstory was removed in this treatment. Large openings covering 20 square feet (6 m^2) resulting from wide skid trails and cutting of treefern were spread

Table 1—*Checklist of plant species tallied in a treefern harvesting study in the Kilauea Forest, Hawaii, 1980*

Scientific name	Common name	Family
Native trees and shrubs		
Broussaisia arguta Gaud.	Kanawao	Saxifragaceae
Cheirodendron trigynum (Gaud.) Heller	Olapa	Araliaceae
Coprosma spp.	Pilo	Rubiaceae
Cyrtandra spp.	Mapele	Gesneriaceae
Ilex anomala H. & A.	Kawa'u	Aquifoliaceae
Metrosideros polymorpha Gaud.	'Ohi'a-lehua	Myrtaceae
Myoporum sandwicense Gray	Naio	Myoporaceae
Myrsine lessertiana A. DC.	Kolea	Myrsinaceae
Perrottetia sandwicensis Gray	Olomea	Celastraceae
Pipturus spp.	Mamaki	Urtiaceae
Tetraplasandra meiandra (Hbd.) Harms	'Ohe	Araliceae
Native forbs		
Astelia spp.	Pa'iniu	Liliceae
Peperomia hawaiiensis C.DC.	Ala'alawainui	Piperaceae
Rubus hawaiiensis Gray	'Akala	Rubiaceae
Stenogyne spp.	Stenogyne	Labiatae
Vaccinium calycinum Sm.	Ohelo	Ericacaeae
Ferns and fern allies		
Asplenium contignum Klf.	—	Aspleniaceae
Athyrium microphyllum (Sw.)	'Akolea	Aspidiaceae
Athyrium sandwichianum Presl	Ho'i'o	Aspidiaceae
Cibotium chamissoi Kaulf.	Hapu'u 'i'i	Dicksoniaceae
Cibotium glaucum (Smith) Hook & Arnott	Hapu'u pulu	Dicksoniaceae
Cibotium hawaiiense Nakai & Ogura	Meu	Dicksoniaceae
Coniogamme pilosa (Brak.) Hieron	Lo'ulu	Adiantaceae
Cyclosorus sandwicensis Brock.	Ho'i'o-kula	Aspidiaceae
Grammitis hookeri (Brack.) Copel	—	Grammitidaceae
Marattia douglassii (Presl) Baker	Mule's foot	Marattiaceae
Microlepia strigosa (Thbvg.) Presl	Palapalai	Dennstaedtiaceae
Pleopeltis thunbergiana Klf.	Laua'e	Polypodiaceae
Polypodium pellucidum Klf.	'Ae	Polypodiaceae
Psilotum nudum (L.) Griseb.	Moa	Psilotaceae
Sadleria pallida Hk. & Arn.	'Ama'u	Blechnaceae
Sphenomeris chimensis (L.) Maxon	Pala'a	Lindsaeaceae
	Filmy fern	Hymenophyllaceae
Introduced shrubs and forbs		
Agrostis avenacea Gmel.	—	Gramineae
Anemone japonica Sueb. & Zucc.	Japanese anemone	P
Buddleja asiatica Lour.	Buddleja	
Cyperus spp.	—	
Erichtites valerionefolia (Wolf) D.C.	Fire	
Geranium carolinionum var. *australe* (Benth.) Fosh	Cra	
Hydrocotyle v		
Hypericum mu		
Juncus tenuis		
Oenothera stri		
Physalis peruv		
Rubus penetra		
Rubus rosaefo		
Solanum nigru		
Sonchus spp.		
Stachytarpheta		
Veronica arver		

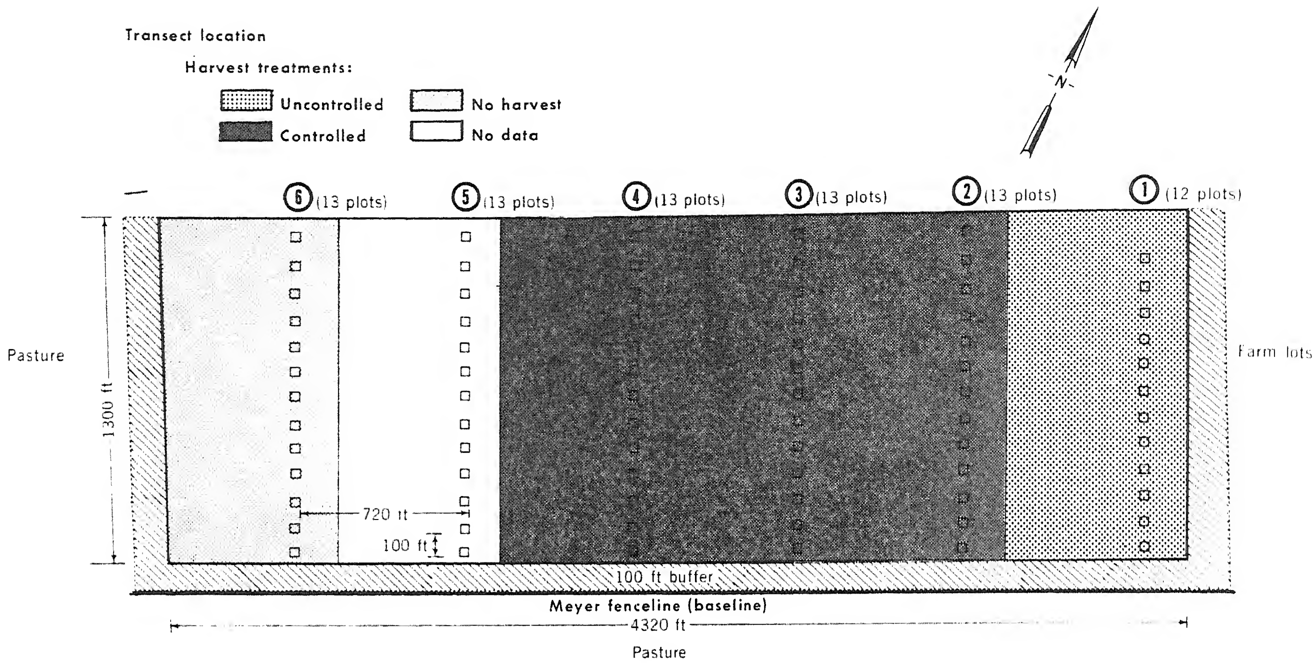
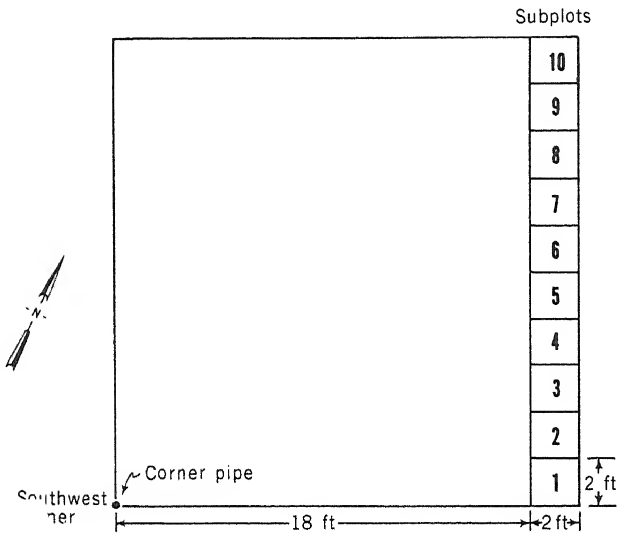


Figure 2—Location of transects, plots, and treefern harvest treatments, Kilauea Forest, Hawaii.



Plot design and dimensions,

Figure 4—A recently-harvested portion of the controlled harvest treatment area. Note that large treeferns were not harvested.

throughout the treatment area. This area is represented by 12 plots in transect 1.

The loggers were not aware of transect or plot locations and measurement dates. About 70 percent of transect 1 had recently been harvested when initial plots were established in 1972. Subsequent reharvesting in transect 1 was done in 1975. By 1977, harvesting had progressed to transect 4. Transect 5 was being harvested at the time of the 1980 remeasurements and, therefore, data for this transect are not included in this report.

Transects 2 through 4 are grouped together for analysis, as they represent the same harvest treatment. Time of harvest in this area varied from 2 to 3 years, but lack of control over harvesting schedules necessitates this grouping.

Harvesting in transect 1 was completed in 1975 and in transects 2 to 4 in 1977. The 1980 data, therefore, represent recovery periods of 5 years for transect 1 and 3 years for transects 2 to 4.

Table 2—*Average height of Hawaiian treefern and density, by number, of treefern and three woody plants in three harvest treatments, Kilauea Forest, 1972, 1977, 1980*

Year	Plots (20 by 20 ft)	Average height Hawaiian treefern (feet)	Plants per acre			
			Hawaiian treefern	Buddleja	Pilo	Mamaki
			Uncontrolled harvest			
[1]1972	12	15.9	1098	0	27	0
1977	12	12.5	517	90	100	218
1980	12	12.2	1007	54	182	363
			Controlled harvest			
[2]1972	39	17.3	960	0	27	0
1977	39	15.3	880	3	45	50
1980	39	15.5	964	3	18	125
			Unharvested			
1972	13	16.0	913	0	16	8
1977	13	15.2	1089	0	59	16
1980	13	14.7	1089	0	25	16

[1] Harvest in 1972—reharvest in 1975.
[2] Preharvest data.

Density of Hawaiian Treefern and Woody Plants

In 1972, density of Hawaiian treeferns taller than 2 feet, measured vertically from the ground to bud tip, ranged from 913 to 1098 treefern per acre (*table 2*). Densities of the treefern among treatment areas did not differ. All density changes described are significant at the 0.05 level. Average height of treefern ranged from 15.9 to 17.3 feet (4.85 to 5.27 m) between treatment areas. Density of treeferns in the uncontrolled harvest area, which had already been partially logged, was surprisingly high, with 1098 treeferns per acre.

In 1977, density of treeferns per acre decreased from 1098 to 517 in the uncontrolled harvest treatment area (*fig. 6*). This decrease was attributed to the reharvest of this area in 1975. Average height of treefern decreased from 15.9 to 12.5 feet (4.85 to 3.81 m). Density in the controlled and unharvested treatment areas remained about the same.

By 1980, the number of treefern per acre in the uncontrolled harvest treatment had returned to preharvest levels although average height decreased slightly from 12.5 to 12.2 feet (3.81 to 3.72 m). In 1980, final densities of treefern per acre between the three treatments did not differ significantly.

Buddleja is an example of a fast growing and prolific seed-producing introduced species that is commonly found in disturbed areas. In sampling all woody vegetation more than 4.5 feet (1.37 m) tall on the main plots, no buddleja plants were found in the study area in 1972 (*table 2*).

In the uncontrolled harvest treatment, 1977 data showed a significant

Figure 5—A skid trail used for 6 months, 1980. This area had the maximum amount of disturbance found in the uncontrolled harvest treatment. Note that treefern tops were left in the skid trail.

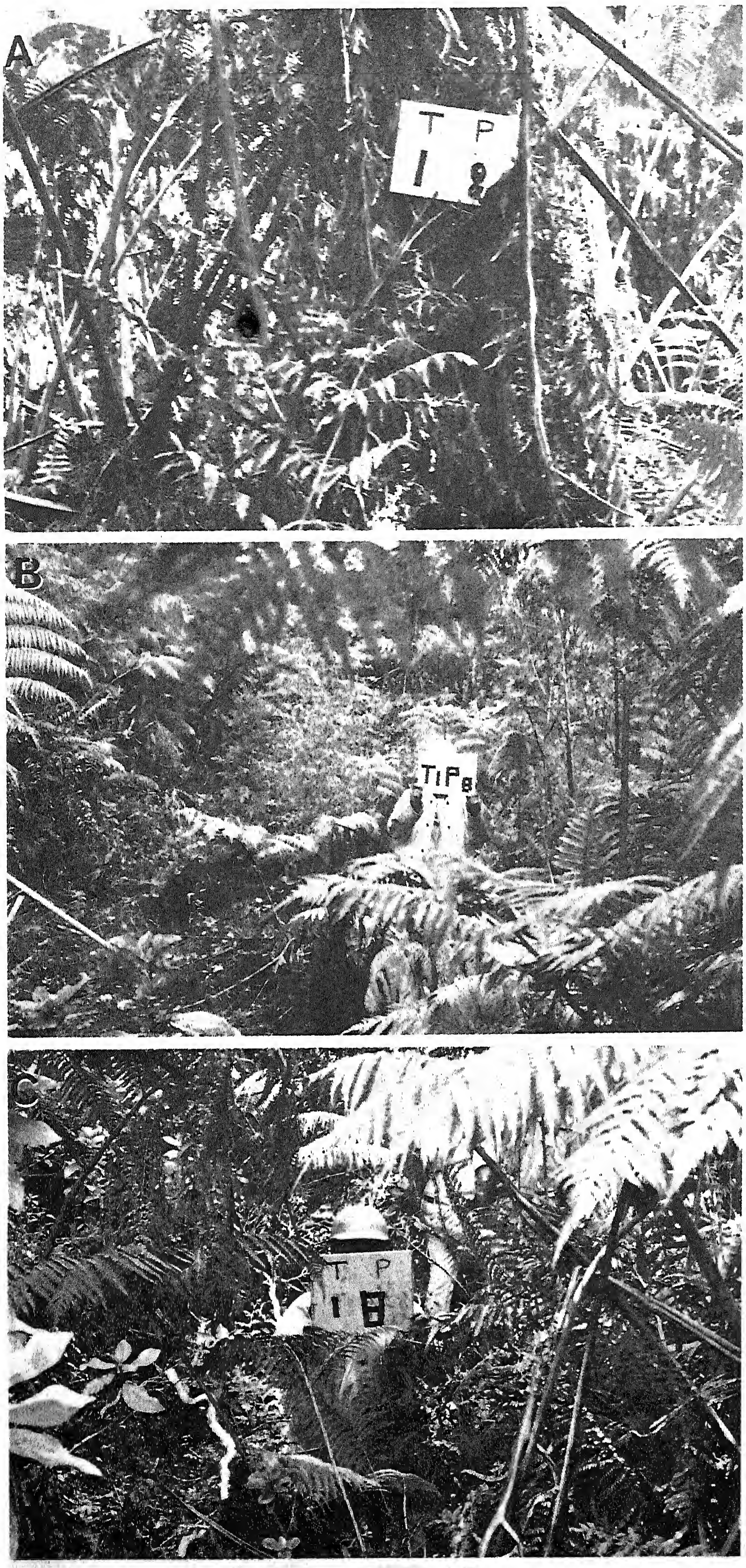


Figure 6—A series of photographs taken at exactly the same location in the uncontrolled harvest treatment. (**a**) An undisturbed treefern forest. (**b**) A more open forest after harvest. Note young mamaki plants in lower left and the invasion of the introduced fireweed in center background. (**c**) Native forest reestablishing on site. Note treefern fronds beginning to dominate the canopy, the growth of the mamaki, and ohelo seedlings in the foreground.

invasion of buddleja plants with 90 plants per acre, with no significant decrease in 1980. From 1977 to 1980, however, average height of buddleja plants decreased from 8.4 to 6.7 feet (2.56 to 2.04 m). The proportion of plants overtopped by surrounding vegetation, predominantly treefern, increased from 10 to 83 percent.

In 1977 and 1980, increases in buddleja density in the controlled and unharvested treatment areas were not significant. Only one buddleja plant more than 4.5 feet (1.37 m) tall was tallied in the controlled harvest treatment and none were tallied in the unharvested treatment.

Pilo and mamaki are pioneer native shrubs reaching 30 feet (9.14 m) tall. The 1972 data showed low numbers of pilo and mamaki in all treatment areas (*table 2*). In 1977 and 1980, in the uncontrolled harvest treatments, both species responded with density increases, although only the mamaki density increase was significant at the 0.05 level. The mamaki density also increased in the controlled harvest treatment in 1977 and 1980.

Native Tree and Shrub Frequency

In 1972, relative frequency of native trees and shrubs among the three treatment areas did not differ significantly. Native tree and shrub species tallied were 'ohi'a-lehua, koa, olapa, olomea, naio (*Myoporum sandwicense* Gray), kanawao (*Broussaisia arguta* Gaud), kopiko (*Psychotria hawaiiensis* [Gray] Fosb.), kolea (*Myrsine lessertiana* A. DC.), pilo, mamaki, mapele (*Cyrtandra* spp.), kawa'u, and ohelo (*Vaccinium calycinum* Sm.). Frequency was measured by a count of subplots in which one or more species were present. All frequency changes described are significant at the 0.05 level.

By 1977, native tree and shrub frequencies increased in both harvest treatment areas (*table 3*). From 1972 to 1977, frequency of native trees and shrubs in the uncontrolled harvest treatment increased from 10.0 to 41.7 percent and in the controlled harvest

treatment from 4.4 to 15.4 percent. Throughout the study period, frequency of native trees and shrubs in the unharvested treatment did not change significantly.

The 1980 remeasurement showed that in the uncontrolled harvest area, frequency of native trees and shrubs changed from 41.7 to 25.8 percent, but this decrease was not statistically significant. From 1977 to 1980, in the controlled harvest area, frequency of native trees and shrubs increased from 15.4 to 26.4 percent.

Table 3—*Relative frequency in subplots of native trees and shrubs, introduced species, and 'ohi'a-lehua seedlings in three harvest treatments, Kilauea Forest, 1972, 1977, 1980*

Harvest	Year	Subplots	Subplot relative frequency: Native trees and shrubs	Introduced species	'Ohi'a-lehua seedlings
			percent		
Uncontrolled	[1]1972	120	10.0	3.3	1.7
	1977	120	41.7	25.8	23.3
	1980	120	25.8	21.7	22.5
Controlled	[2]1972	390	4.4	2.3	0.0
	1977	390	15.4	7.4	5.6
	1980	390	26.4	7.4	7.2
Unharvested	1972	130	5.4	0.0	0.0
	1977	130	10.0	0.0	2.3
	1980	130	8.5	0.8	0.0

[1] Harvest in 1972—reharvest in 1975.
[2] Preharvest data.

Introduced Species Frequency

Initial measurement in 1972 showed no differences among the frequency of introduced species between treatment areas (*table 3*). Introduced species include woody and herbaceous vegetation.

In 1977, however, the data showed increases in introduced species frequencies in both harvesting treatments. Compared to 1972, a greater frequency of introduced species was tallied in the uncontrolled harvest treatment than in the controlled harvest treatment.

In 1980, frequency of introduced species was 21.7 percent for the uncontrolled harvest treatment, 7.4 percent for the controlled harvest, and 0.8 percent for the unharvested treatment. From 1977 to 1980, frequency of introduced species in harvest treatments did not decrease.

'Ohi'a-lehua Seedling Frequency

In 1972, there were no differences in the relative frequency of 'ohi'a-lehua seedlings among the three treatment areas. All seedlings were less than 4 inches (10.2 cm) tall with no sapling-size 'ohi'a-lehua found in any of the treatment areas throughout the study period.

From 1972 to 1977, frequency of 'ohi'a-lehua seedlings in the uncontrolled harvest treatment increased from 1.7 to 23.3 percent and in the controlled harvest treatment from 0 to 5.6 percent. The 1980 measurement showed no change in either harvest treatment. The 1980 'ohi'a-lehua seedling frequency in the uncontrolled harvest treatment was greater than in the controlled harvest treatment.

Throughout the study, frequency of 'ohi'a-lehua seedlings in the unharvested treatment did not change significantly.

DISCUSSION

Any disturbance to the native Hawaiian forest may result in temporary or permanent changes in plant composition. Major disturbances, such as treefern harvesting, provide the opportunity for invasion of aggressive introduced species that may prevent native species from being reestablished.

In the controlled harvest treatment, initial invasion by introduced species was considerably less than in the uncontrolled harvest treatment. Most of the remaining introduced species tallied in 1980 were scattered plants overtopped by native vegetation, predominantly treefern. Only one introduced shrub more than 4.5 feet tall was found in the controlled harvest treatment plots. There were no localized areas found where introduced species had dominated the site, preventing native plant reestablishment.

In the controlled harvest treatment, native trees and shrubs increased considerably, with a final frequency three times that found in the unharvested treatment. Much of this increase resulted from the invasion of pioneer native shrubs, such as pilo and mamaki, but tree seedlings of 'ohi'a-lehua, olapa, kawa'u, and kolea also increased in number.

Average number of treefern per acre remained constant in the controlled harvest treatment. Pre- and postharvest measurements showed no significant differences in number of treeferns per acre between the controlled and unharvested treatments. Reduced average height of tallied treefern in the controlled harvest treatment, however, indicates regrowth from newly established treefern tops scattered in the skid trails as well as ingrowth of smaller and already established, unharvested fern. This indicates that Hawaiian treefern has a strong and aggressive capacity for reestablishment in disturbed areas.

In the uncontrolled harvest treatment, initial invasion by introduced species was substantial with no significant decrease over time. In certain localized areas, introduced forbs and grasses predominated, to the exclusion of native plants. In a similar study, the extent of weedy plant invasion increased with higher levels of irradiance on the forest floor, a condition that

was created by the uncontrolled harvest treatment.[4]

In other areas in the uncontrolled harvest treatment, native woody plant diversity and frequency increased. An increase of 'ohi'a-lehua seedlings in the uncontrolled-harvest area was significant. Considering the trade-off between a residual introduced species component and an increase in native woody plant frequency, the uncontrolled method of harvesting should not be encouraged.

In the uncontrolled harvest treatment, Hawaiian treefern again showed a strong capacity for reestablishment with an increase from 517 to 1007 per acre from 1977 to 1980.

This study was conducted in a healthy, native hapu'u forest that initially contained almost no introduced plants. Uncontrolled hapu'u harvesting in other Hawaiian forests that already contain some introduced plants could encourage the introduced components to predominate to the exclusion of the native components, and should not be encouraged.

Acknowledgment:

Research in Hawaii by the Forest Service, U.S. Department of Agriculture, is carried out in cooperation with the Division of Forestry and Wildlife, Hawaii Department of Land and Natural Resources.

NOTES

[1] Nelson, Robert E.; Hornibrook, E. M. *Commercial uses and volume of Hawaiian treefern.* U.S. Forest Serv. Tech. Paper PSW-73. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1962. 10 p.

[2] Although under private ownership, the Kilauea Forest is Conservation District Land, and a State Land Use Law gives jurisdiction to the Board of Land and Natural Resources over certain uses of these lands.

[3] U.S. Department of Agriculture. *Soil survey of the Island of Hawaii.* Honolulu, HI: Soil Conservation Service, State of Hawaii; 1973; 115 p.

[4] Burton, Philip J. *Plant invasion into an ohi'a-treefern rain forest following experimental canopy opening.* 1980 Proceedings, Third Conference in Natural Sciences; 1980 June 4; Hawaii Volcanoes National Park. (In process)

The Author:

MICHAEL G. BUCK is a resource forester with the Hawaii Division of Forestry and Wildlife. He works with the Division's resource inventory, research, and remote sensing programs. He holds a B.S. degree in resource management from State University of New York School of Environmental Science and Forestry, Syracuse, New York (1976). He has been with the Division since 1977.